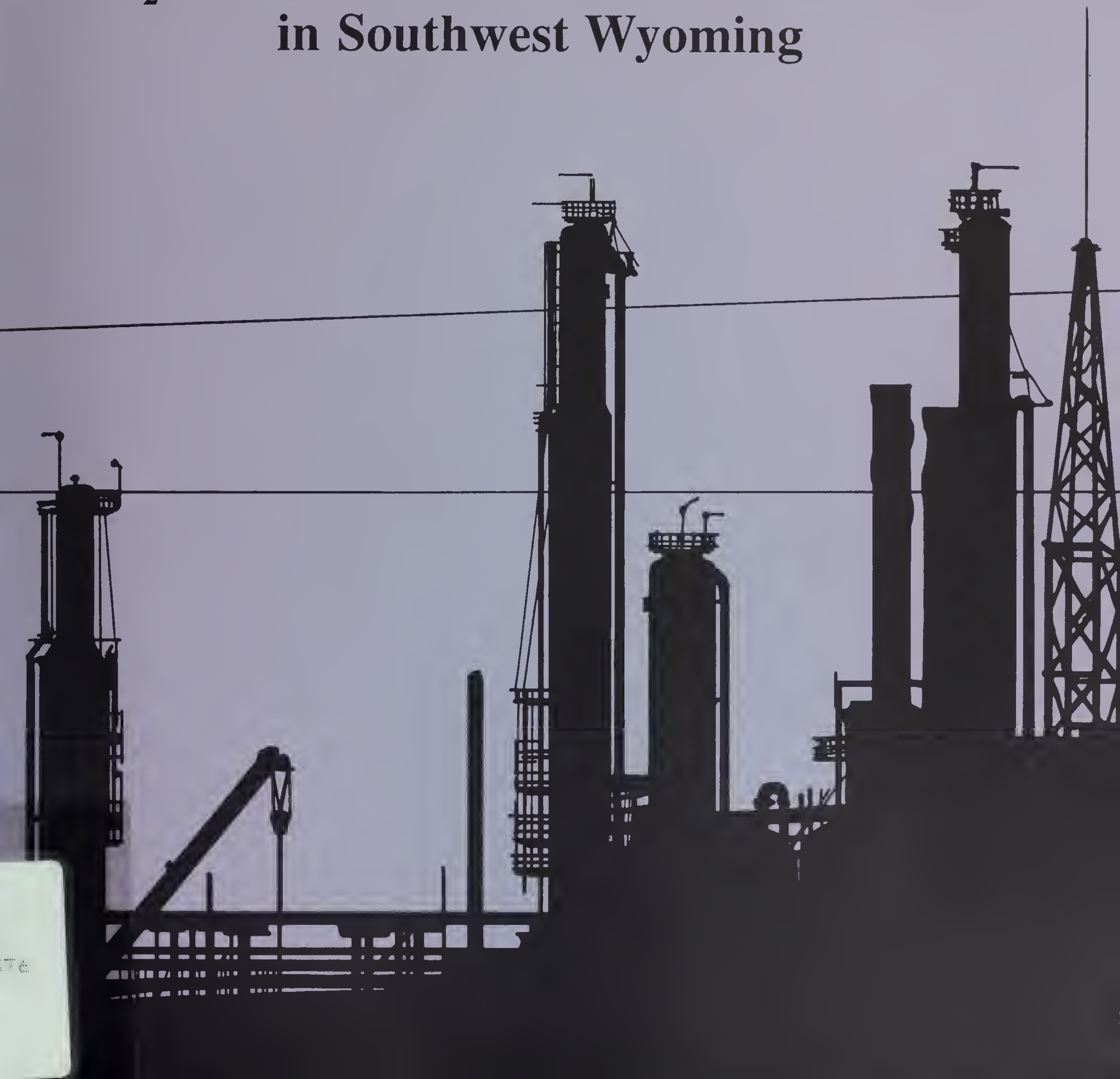
Technical Note 376

Regional Risk Identification Analysis Applicable to Resource Development of H_2S-Contaminated Natural Gas Fields in Southwest Wyoming



BLM Technical Note 376

Regional Risk Identification Analysis Applicable to Resource Development of H_2S-Contaminated Natural Gas Fields in Southwest Wyoming

by

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ABSTRACT

Dangerous concentrations of hydrogen sulfide (H_2S) have occurred through accidental release of sour natural gas from wells and pipelines (Layton et al. 1983). Local, terrain-influenced, meteor-ological conditions can control the seriousness of these events. In order to plan the development of H_2S-contaminated natural gas fields in Wyoming, the U.S. Bureau of Land Management (BLM) had to identify areas where air-quality impacts (dangerous concentrations) were likely, as well as those areas where they were unlikely. To accomplish this, a regional risk identification was performed for two Environmental Impact Statements prepared for the BLM's Kemmerer, Wyoming, Resource Management Plan in 1985. In this analysis, map overlays of known H_2S formations, geological hazards, population centers, and meteorological dispersion potential were compiled. This compilation was used to highlight areas where the air quality-related gas resource development risk is relatively high or low. Air resource modeling was conducted using component models of the Topographic Air Pollution Analysis System (TAPAS) developed by the U.S. Forest Service, the BLM, and the Colorado State University.

INTRODUCTION

The objectives of air resource management for Federal land management agencies include reducing the potential for adverse impacts on the Federal lands under their jurisdiction. To date, this has focused on managing smoke from prescribed fires, mitigating effects of new major pollution emission facilities, and evaluating the potential air quality impact of other management actions (mineral leasing). Resource values, such as visibility, soil chemistry, vegetation, and aquatic ecosystems, are included. Proper planning of the location of a source, allowable levels and types of emissions, and the timing of the emissions can reduce, often substantially, the risk that adverse impacts will occur. This process may also consider the potential for, and probability of, accidental pollutant releases of toxic materials. The quantitative assessment of the risk of damage from these releases requires the use of sophisticated computer dispersion models.

To support these responsibilities, the U.S. Bureau of Land Management (BLM) and the U.S. Forest Service have collaborated in the development of the Topographic Air Pollution Analysis System (TAPAS). TAPAS includes a number of air resource management modules which provide computerized tools for land managers to manage air resources.

Air quality-related impacts from the development of natural gas fields in Wyoming are of particular interest since relatively high levels of H_2S, a highly toxic chemical, are associated with the gas. Assessing the health risks of a potential sour gas (H_2S-contaminated) release involves estimating the emission rate of hydrogen sulfide and how it is released, predicting downwind concentrations, analyzing potential health effects, and reviewing safety methods to minimize the potential health risk (Layton et al. 1983).

Quantification of actual risks on a regional scale requires data on a number of variables which are generally unavailable to the investigator. Specifics of the geology and thermal histories of potential, often unexplored, fields make the accurate estimation of H_2S contamination impossible. In addition, risks which are compounded by demographics are almost impossible to predict with changing economies. Classic risk analysis techniques gather and analyze parameters and variables—whose magnitude is known with some degree of confidence—to produce a statistical average of risk which can be compared with other risk issues with some degree of meaning. These techniques were employed in an air resources technical report, included in the Riley Ridge Natural Gas Project Environmental Impact Statement (BLM 1983).

This paper describes a four-level hierarchical analysis for dealing with toxic air pollutants within the framework of responsibilities of Federal land managers. It is proposed that risk identification be initially applied for regional-scale sour gas planning. The paper documents an application of TAPAS models to aid in the regional risk identification and provides specific examples from southwestern Wyoming.

RISK IDENTIFICATION AND ASSESSMENT

The evaluation of potential air-quality impacts is often organized into a series of analysis levels. The early levels, often termed screening techniques, are easily applied and err on the side of safety (conservatism). Later levels incorporate complex modeling techniques requiring specific data to better quantify estimates of potential impacts. The investment of technical and fiscal resources increases dramatically as one progresses from the simple and conservative to the complex and more realistic.

To assess the risk from a potential accidental release of sour natural gas, a four-level approach is suggested.

Level I: Regional risk identification involves compiling information that provides an overview of planned regional resource activity. Compiled information might include air pollution sources, geologic hazards, meteorological conditions, population statistics, and other similar data. The objective of this analysis is to define broad geographic areas where specific air-quality problems could occur. Higher level analyses could then be performed for sources within these identified problem areas. This level of analysis suits the preparation of Federal land management plans such as U.S. Forest Service Forest Management Plans, and Resource Management Plans for the BLM. This paper presents an example of such an assessment.

Level II: Source-specific screening techniques which can be applied without detailed source-specific data. A specific example, useful as a preliminary H_2S screening technique, has been presented as Onshore Oil and Gas Order Number 2 (Draft 43 CFR, Part 316, Federal Register 10/15/84). This algorithm estimates a radius of exposure for various ambient levels of H_2S, based only on an estimated gas well flow.

This screening technique does not directly consider onsite meteorological conditions, the dynamics of the gas emissions (i.e., plume rise), terrain influences, or other factors. The technique is designed to produce quick and easy assessments close to the point of release. If this technique yields results that require special precautions (as described in the draft regulations), or in cases where an accidental release could be influenced by local conditions (meteorology, terrain, etc.), the application of more comprehensive modeling techniques is appropriate.

Level III: Source-specific diagnostic analysis based on air dispersion modeling can use data on emission rates and meteorology. Meteorological parameters (wind speed, wind direction, atmospheric stability) define the range of conditions that can affect plume transport and diffusion. Best estimates of source emissions and emission characteristics are required to yield realistic results. Turner (1969) compiled a workbook on atmospheric pollutant dispersion which presents a series of nomograms that allow for convenient downwind pollutant concentration estimations. Layton et al. (1983), detail how such dispersion formulations can be directly applied to estimate potential H_2S impacts and health and safety risks. The U.S. Environmental Protection Agency has published a series of computer programs entitled "User's Network for Applied Modeling of Air Pollution (UNAMAP)," that includes methods to estimate impacts from single and multiple sources in a variety of spacial and temporal configurations. Several of these models have been included in TAPAS (Fox et al. 1983). By completing several simulations with models of this type for a realistic number of meteorological and emission scenarios, a range of expected pollution impacts can be determined.

Coupling concentration predictions with estimates of the probabilities of their occurrence gives an assessment of risk. To lower the probability of adverse effects, the probability of occurrence of pollution release can be lowered. The BLM has used this technique to assess risks for individual projects against other related risks (Table 1) as part of its analysis for the Riley Ridge Natural Gas Project EIS (BLM 1983).

Table 1. Annual risk to southwestern Wyoming populated areas anticipated from Riley Ridge sour gas development, compared with risks from accidents and natural disasters (BLM 1983).

Populated area	Individual associated H_2S-development risk
Calpet	0.00023
Labarge	0.00013
Big Piney	0.00008
Marbleton	Negligible
Fontenelle Recreation Area	Negligible

General risk-producing activity	Individual associated risk (annual)
Smoking	0.005
Automobile	0.00025
Industrial	0.00017
Falls, air crashes	0.000077
Lightning	0.000005
Tornadoes	0.0000044

Note: 1. Smoking for 20 cigarettes/day.
2. Risk values such as 0.00013 mean 13 chances per 100,000.
3. Negligible means that modeling indicated no risk.

Amoco Production Company, for example, in constructing a sour gas pipeline, minimized potential emission volumes and rates by installing pipeline block valves to limit potential ambient H_2S dosages to 250 ppm/10-second exposure (Amoco 1984).

Level IV: In some cases, such as accidental release of toxic gases, real-time emergency assessment techniques are needed. In these instances, predicting models which provide insight into where pollutants will go, and at what concentration they will arrive, must be coupled with specifics of terrain and localized meteorological conditions.

Level IV analyses are applied to evaluate specific short-term events and may incorporate calculations involving physical, chemical, and biological properties of the gas (buoyancy, reaction rates and secondary products, types of toxic reactions). Analyses based on these sophisticated models require local real-time meteorological data. The models employed may be formulated for one specific topographic area, and be applicable to a specific source or source type. Ideally, these models would be relatively easy to execute and would quickly return useful insights in threatening situations.

SOUTHWESTERN WYOMING HYDROGEN SULFIDE REGIONAL RISK INDENTIFICATION ANALYSIS

Substantial natural gas resources exist in western Wyoming, eastern Utah, and eastern Idaho. Some of the geologic formations under development yield gas that is as high as 19% hydrogen sulfide. Above 250 ppmv, H_2S appears toxic to many forms of life. Thus, accidental releases of H_2S can potentially result in catastrophic events with loss of wildlife (USGS 1981), or loss of human life (Layton et al. 1983).

To identify the risks of developing the gas resources in southwestern Wyoming, an H_2S Regional Risk Identification was performed. The risk-identification procedure included compiling map overlays of a variety of parameters related to the potential for accidental H_2S release, and the potential for significant impacts to occur from these releases. The compiled information includes map overlays of:

- Oil and gas fields that produce H_2S
- Atmospheric dispersion potentials
- Pollution trajectories
- Human population
- Historic earthquake epicenters
- Areas of high landslide potential

All the compiled information and a discussion of the composite regional risk identification map are provided in the following subsections.

Southwestern Wyoming Study Area—Figure 1 is a computer-generated base map of the south-western Wyoming regional study area, including relevant portions of BLM's Pinedale, Kemmerer, and Lander Resource Areas, containing a diversity of activities, including sour natural gas development. Figure 2 is a computer-generated contour map of the area.

Location of Oil and Gas Fields that Produce H_2S—The locations of known H_2S-producing oil and gas fields (Figure 3) were compiled using best available knowledge by BLM Wyoming specialists. The majority of the contaminated fields exist in the southwest quadrant of the study area. These fields outline areas where H_2S releases could occur.

Pollution Potential Index Analysis—A pollution potential index (PPI) analysis for the area was developed. This analysis varies from the more common approaches that are source-dependent. The PPI approach evaluates the relative dispersion potential of the local topography. It is based on a model of air flow patterns as influenced by topography and meteorological conditions. The models used are part of TAPAS. Terrain data are retrieved from a data tape and structured into a specially formatted file after an appropriate analysis area is identified. Climatological data are then chosen for the analysis; in this case, data from Rock Springs, Wyoming, for a 5-year period (1967-1971) were used. A TAPAS flow simulation model, WINDS, was then executed using the gridded terrain data for each chosen meteorological flow simulation. Each of the flow simulations are then overlayed and areas of divergence or convergence delineated.

The pollution potential index, as calculated within TAPAS using the WINDS model (Fox et al. 1983), is a function of wind speed and the Gaussian dispersion coefficients for Class E stability. The index is defined as:

$$PPI = M/U$$

where M is a numerical coefficient based on assuming Class E stability, a source receptor distance of 1 km, and standard EPA dispersion curves. Its magnitude is approximately 300 (Dietrich and Mussard 1985).

and U is the wind speed in meters per second (mps) at a grid point, based on results from the wind model. All wind speeds less than 0.5 mps are assumed to equal 0.5 mps.

The pollution potential index is based on the observation that pollution more readily accumulates in protected areas, characterized by low wind speeds, than in areas that experience moderate winds. Thus, a higher PPI would be calculated for the low wind-speed areas. E-stability assumptions (Turner 1969) are applied to simulate representative worst-case conditions relating to a very stable atmosphere. A 1,000-meter source receptor distance was selected because it is representative of the general distance between grid points used in applications of the WINDS model.

The index is calculated and should be generally interpreted, to represent estimated ranges of pollution stagnation potential. The index ranges from 0 to 600, but the index values are usually simplified into four ranges.

Pollution potential index values	Verbal description
<50	Low
50-150	Medium
150-300	High
>300	Very High

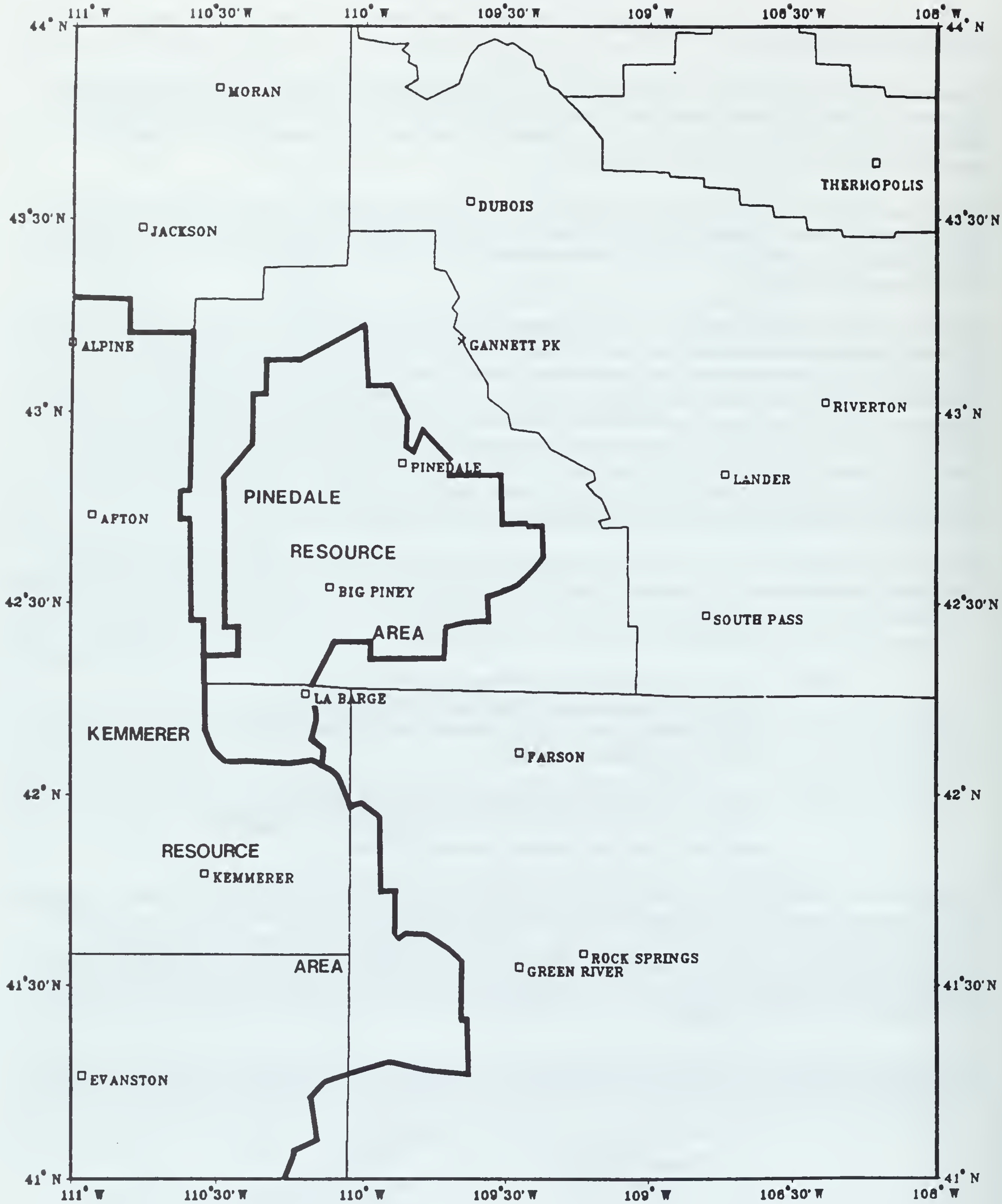

Figure 1. Base map of the southwestern Wyoming regional study area 3, with towns and county boundaries indicated.

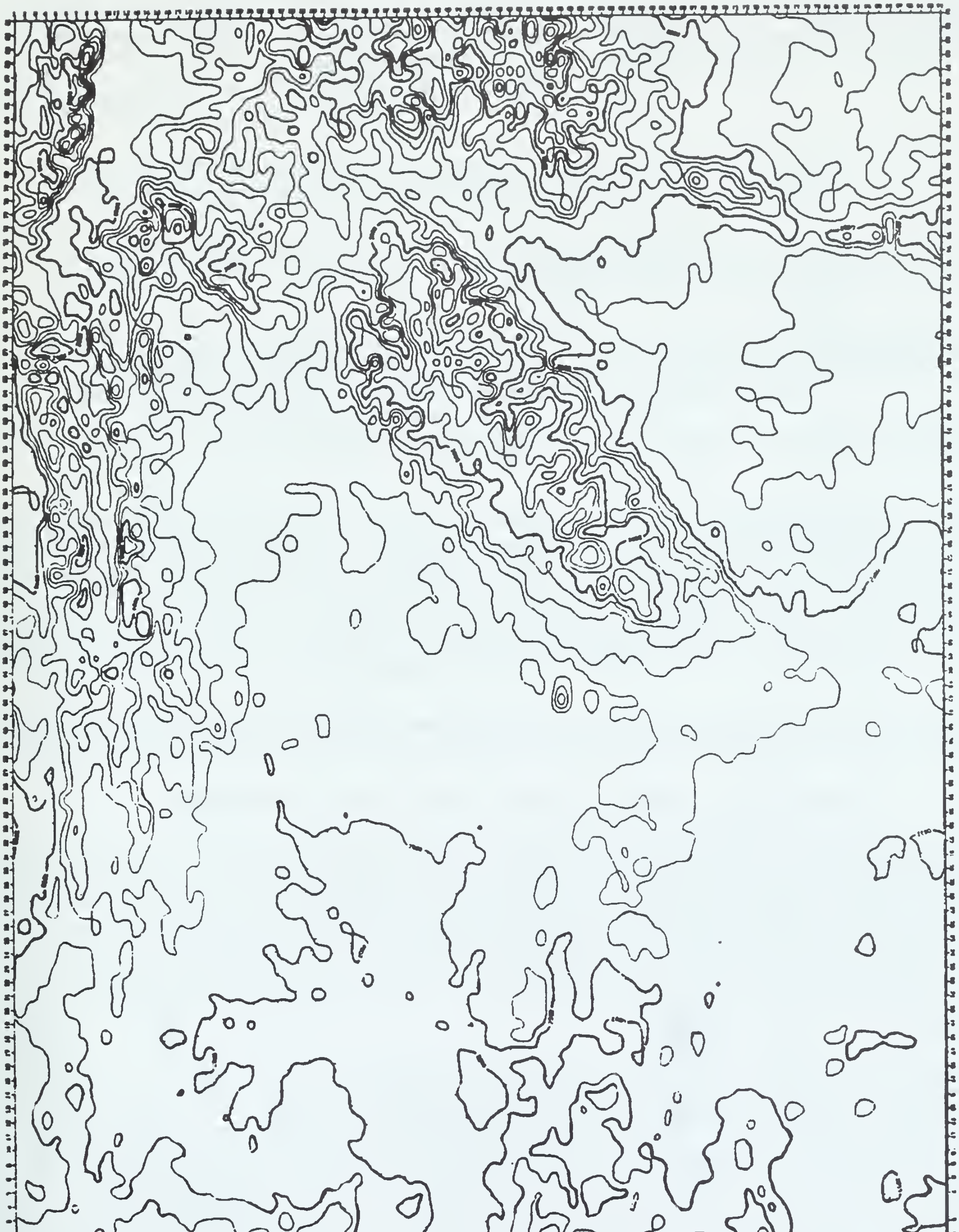

Figure 2. Topographic contour map of the southwestern Wyoming regional study area (contour interval = 200m).

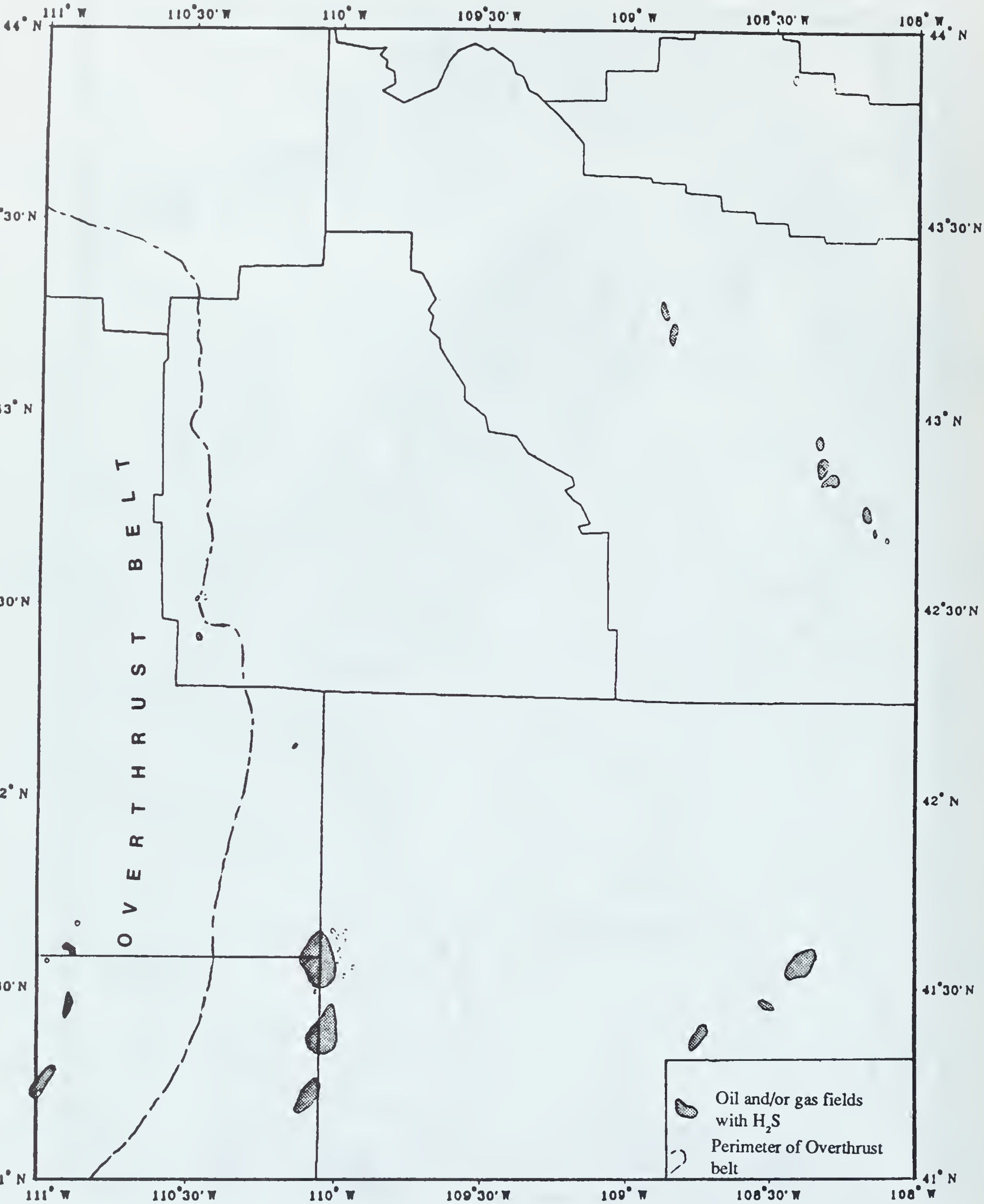

Figure 3. Location map of oil and gas fields that produce H_2S in the southwestern Wyoming regional study area.

Annual pollution-potential indices are very useful to the land manager to delineate areas where pollutant release could endanger sensitive resources. In this example, the annual indices give insight on areas where accidental release of H_2S gas might be most dangerous due to poor dilution. To complete this analysis, individual wind fields over the study area were combined by considering the frequency of each modeled wind condition to yield an annual pollution potential contour map
(Figure 4). The analysis was performed by:

1. Selecting representative annual wind frequency distribution data for the study area. The frequency distribution is generally reduced to 16 wind directions by 6 wind-speed classes.

2. Executing a WINDS model simulation and pollution potential index analysis for each wind-speed/ wind-direction class. Each analysis will yield a pollution potential for each grid point in the study area.

3. Combining the index results from each of the model runs into a composite annual pollution-potential index. During this process, the final indices from each WINDS simulation are weighed by frequency of occurrence for the wind speed/direction class they represent.

4. Preparing a contour analysis (with graphics products) of the resulting annual pollution-potential grid.

The wind frequency distributions for the study area would have been chosen to represent specific conditions rather than average annual conditions. This might be useful to analyze a specific accidental release. Because winds are often correlated with atmospheric stability, individual pollution-potential index analyses can be performed for several stability wind frequency distributions to provide a range of average to potential worst-case conditions. For example, individual pollution-potential index maps may be produced to represent the pollution-potential index under all stabilities (A through F), E-stability (stable to very stable atmospheric conditions), and/or F-stability (extremely stable).

In addition to the application in this paper, annual pollution-potential analysis maps provided general guidance for planning for a wide range of land uses.

REGIONAL POLLUTION TRAJECTORY ANALYSIS

Major development of natural gas fields and associated industry in southwestern Wyoming is expected, or is underway in some areas. The Exxon Shute Creek natural gas sweetening facilities near Labarge, Wyoming, and the Chevron phosphate fertilizer plant near Rock Springs, Wyoming, are examples of new air pollutant emission sources in the study area. To provide an overview of how air pollutants released in the study area may be transported by prevailing winds, a plumb trajectory analysis was performed for five hypothetical sources. The five sources were distributed within major natural gas resource areas to provide insight into the potential development of this resource
(Figure 5).

CITPUFF, a TAPAS plume transport and diffusion model (Ross et al. 1985) was used to determine plume trajectories. Based on Rock Springs wind data, the wind comes most frequently from the west quadrant (235-315 degrees azimuth). Wind observations in this quadrant occur about 60% of the time. The WINDS model was applied to simulate the flow of wind over the study area for prevailing southwest, west, and northwest flows. Steady-state wind flows were assumed for each of the three modeled directions. The results of the WINDS simulations were then used as the basis for the CITPUFF simulations. It should be noted that plume trajectories are theoretical simulations which do not incorporate three-dimensional wind and turbulence patterns. The modeling technique cannot account for all possible influences on plume dynamics under complex wind conditions common in mountainous areas. This analysis does give an indication of generalized worst-case trajectories where meteorological assumptions are simplified due to scarcity of observations. The results of the plume trajectory analysis are presented in Figure 5.

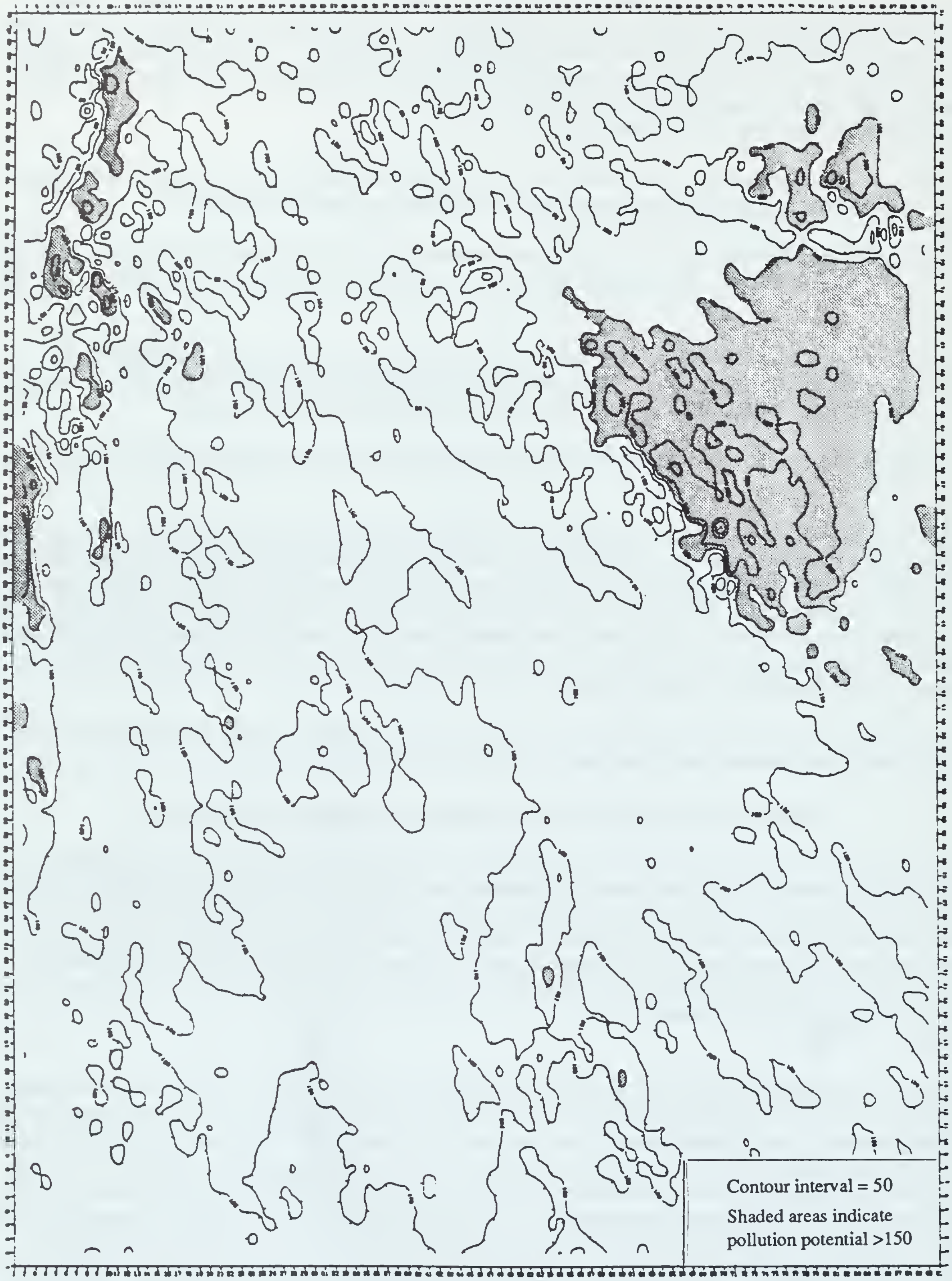

Figure 4. *Pollution potential index contour map for the southwestern Wyoming regional study area under F-stability conditions occurring 17% of the time.*

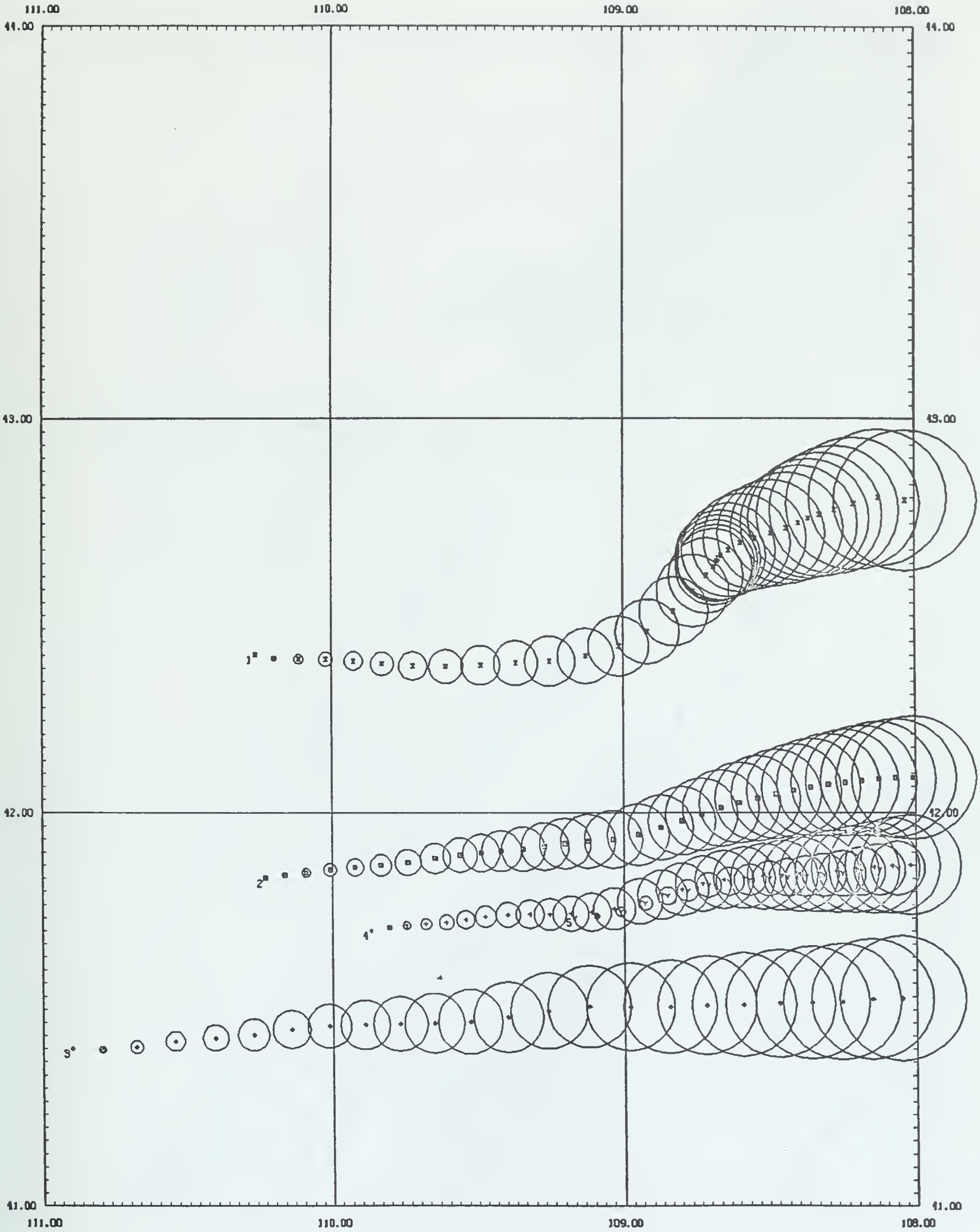

Figure 5a. Estimated plume trajectories from five hypothetical sources under steady state west winds.

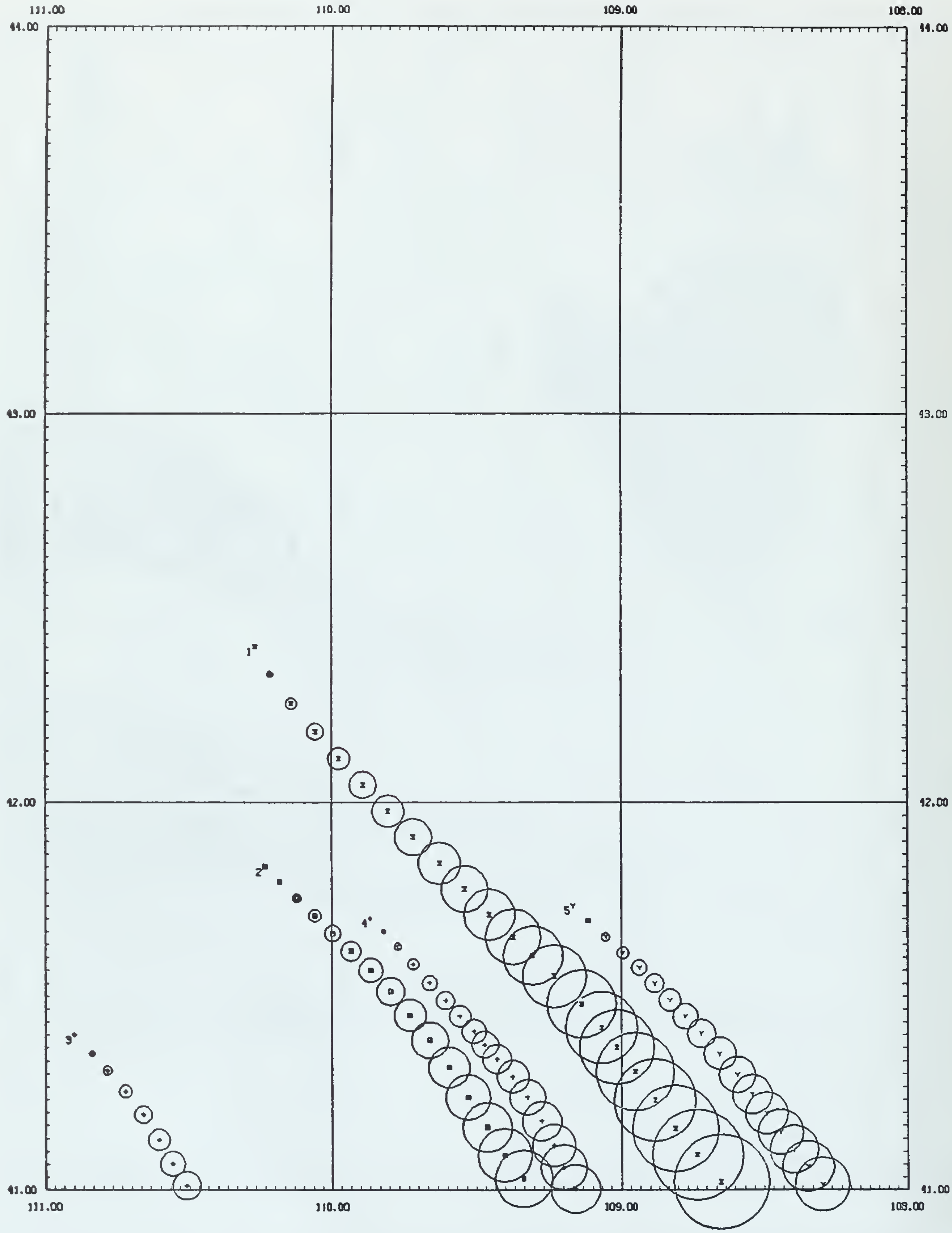

Figure 5b. Estimated plume trajectories from five hypothetical sources under steady state northwest winds.

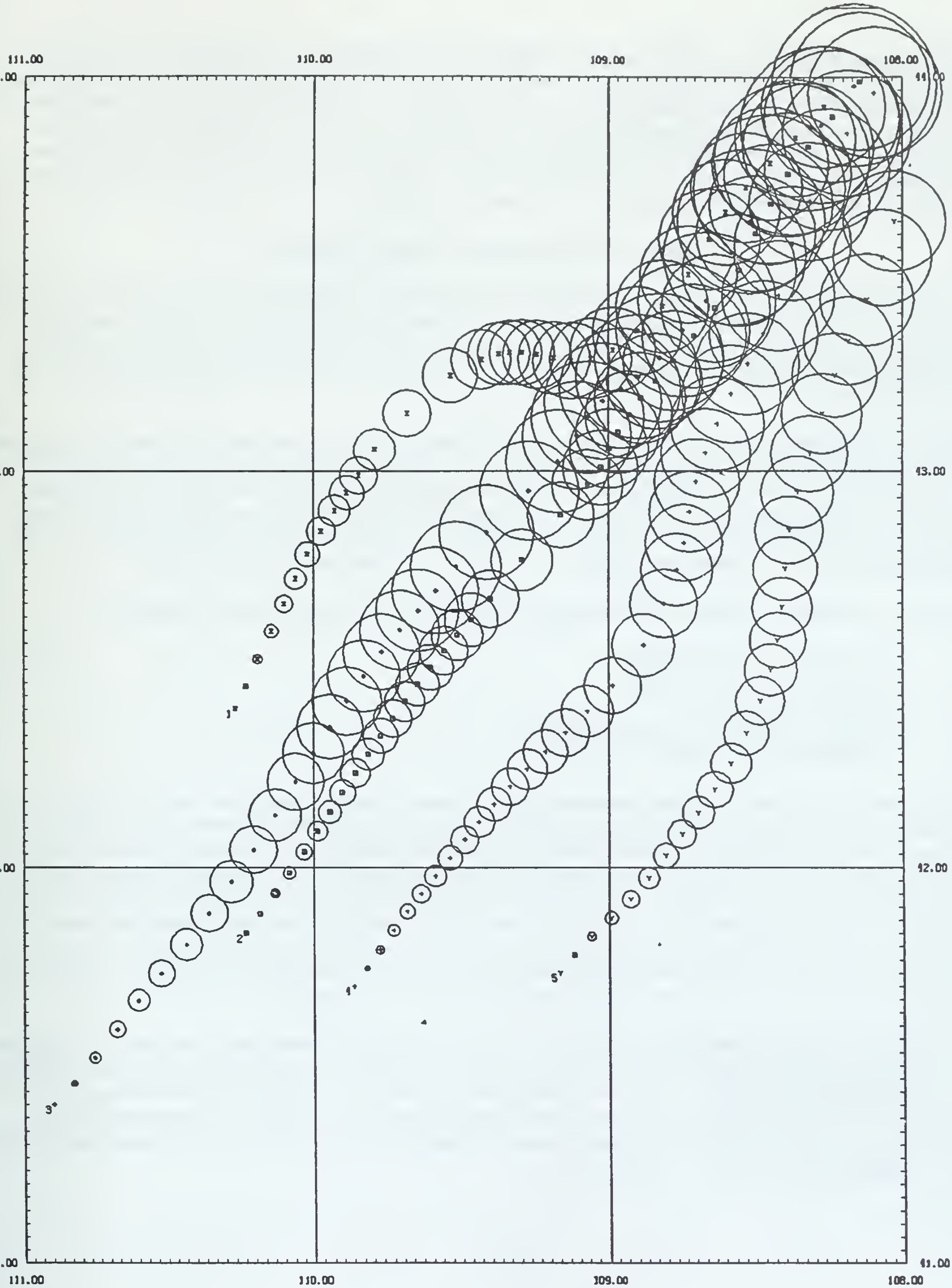

Figure 5c. Estimated plume trajectories from five hypothetical sources under steady state southwest winds.

Plume trajectory analysis can also be useful in predicting the actual flow of a sour gas release over terrain. Applied to a producing well for which specific emission parameters can be calculated (i.e., calculated absolute open flow [CAOF], gas temperatures), plume trajectory analysis can give planners insight into which meteorological conditions embody the greatest risk. By applying this technique to accidental releases after the fact, the route travelled by the plume during the incident can be determined. Both of the above-mentioned activities, Level III analyses by our classification scheme, can improve planning of resource development in sensitive areas and, in extreme cases, aid in the assessment of liability.

RESOURCE ISSUE COMPARISONS

The potential effect that air pollution may have on human population is obviously the most important factor in risk assessment. For this H_2S Regional Risk Identification Analysis, population statistics from the 1980 census were compiled and mapped, with centers of population reduced to ranges of 500-1,000, 1,000-2,500, 2,500-10,000, and 10,000-25,000 persons (Figure 6). This population map was overlayed on potential H_2S sources (Figure 3).

Earthquakes and landslides can cause damage to gas wells and pipelines accentuating the potential for dangerous releases. A historic earthquake epicenter map within the study area was compiled from information gathered by the Bureau of Land Management. This map (Figure 7) shows that the majority of earthquakes have occurred in the northwest quadrant of the study area, and that some earthquakes have occurred in sour gas fields. Potential landslide areas were also mapped utilizing data gathered by the BLM (Figure 8). From this information, it can be seen that landslide potential does exist near some sour gas fields.

Finally, a composite map (Figure 9) was prepared depicting the following risk-related parameters:

- sour oil and gas fields (Figure 3)
- pollution potential (Figure 4)
- population (Figure 6)
- historic earthquake epicenters (Figure 7)
- landslide areas (Figure 8)

Areas where two or more risk-related parameters coexist identify risk-sensitive areas. Areas of high air resource or PPI-related risk are projected to be in the northeast and southwest quadrants of the study area. For example, Evanston, Wyoming, is located within a sour gas area (as high as 19% H_2S by volume in some produced gas); it has a population greater than 10,000 and has experienced earthquakes in the past. Although the regional analysis did not indicate a high PPI for this area, further analysis using localized meteorology and a finer topographic grid spacing for model simulations may be warranted. In general, where risk-related parameters coexist, care should be taken to perform adequate analysis of the potential air-quality impact from each proposed well. At least a Level II, and possibly a Level III, analysis should be required. If these analyses indicate problems, prudent management would dictate a Level-IV analysis.

In most of the study area where H_2S-rich fields exist, other indications of potential risk are absent. In some of the major fields located midway between Kemmerer and Green River, no earthquakes, landslides, high PPIs coupled with population centers, exist. Areas designated as "critical" for sensitive resource values (e.g., elk calving grounds) are also not present. The risk of resource development in these areas appears to be low. Management alternatives that consider development in these areas could be favored over management alternatives that consider development in higher-risk areas.

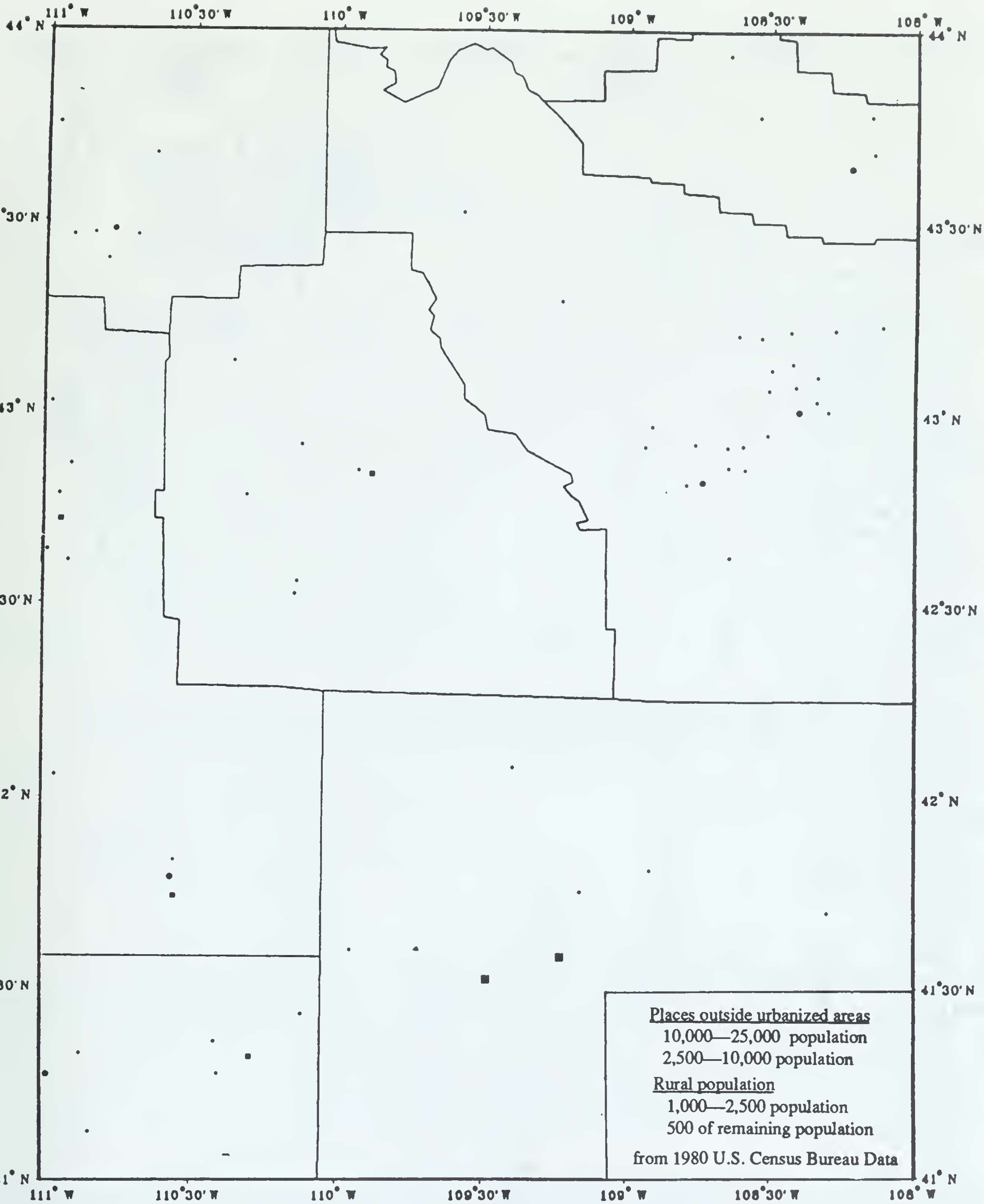

Figure 6. Population map of the southwestern Wyoming regional study area.

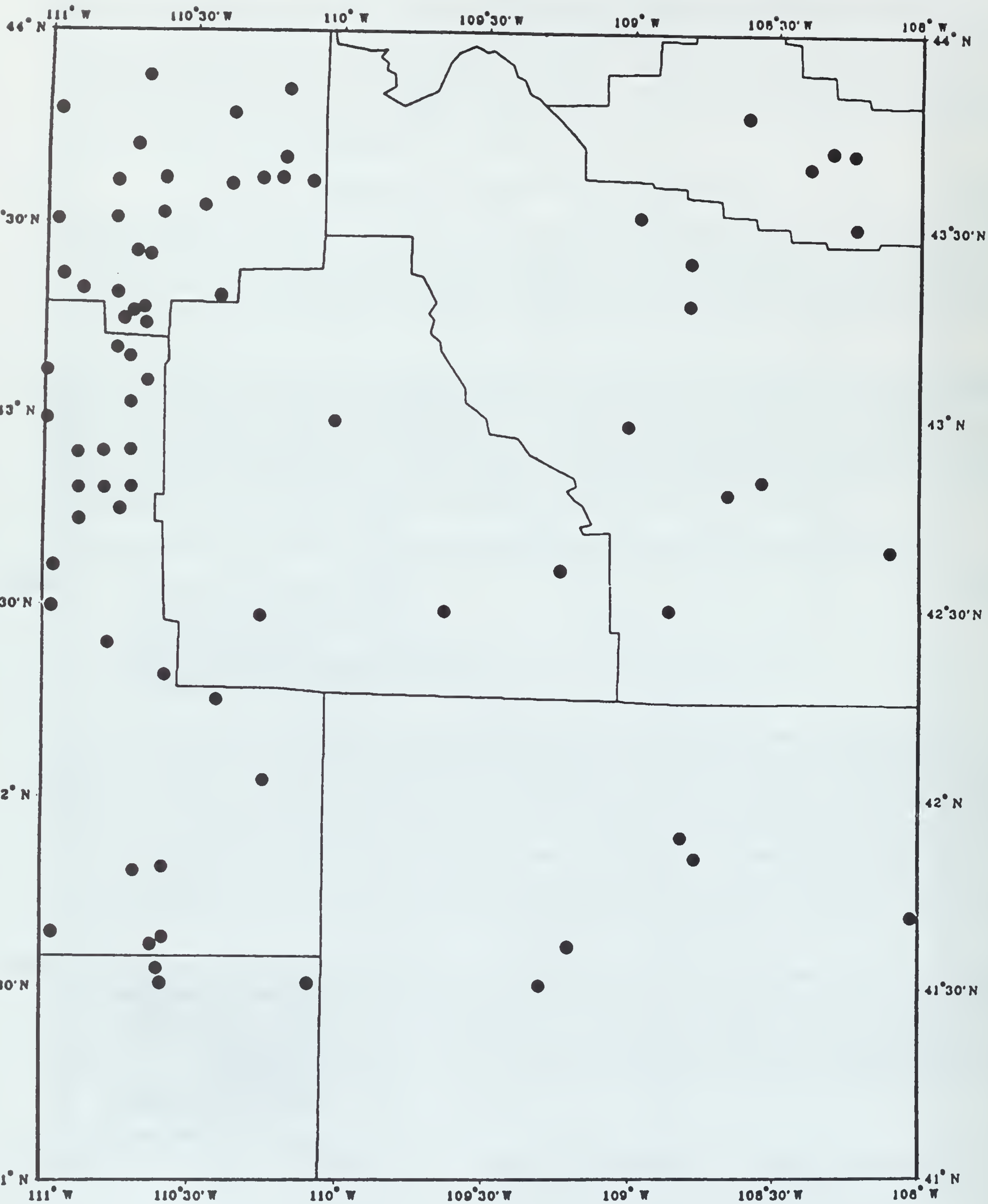

Figure 7. Historic earthquake epicenter location map of the southwestern Wyoming regional study area.

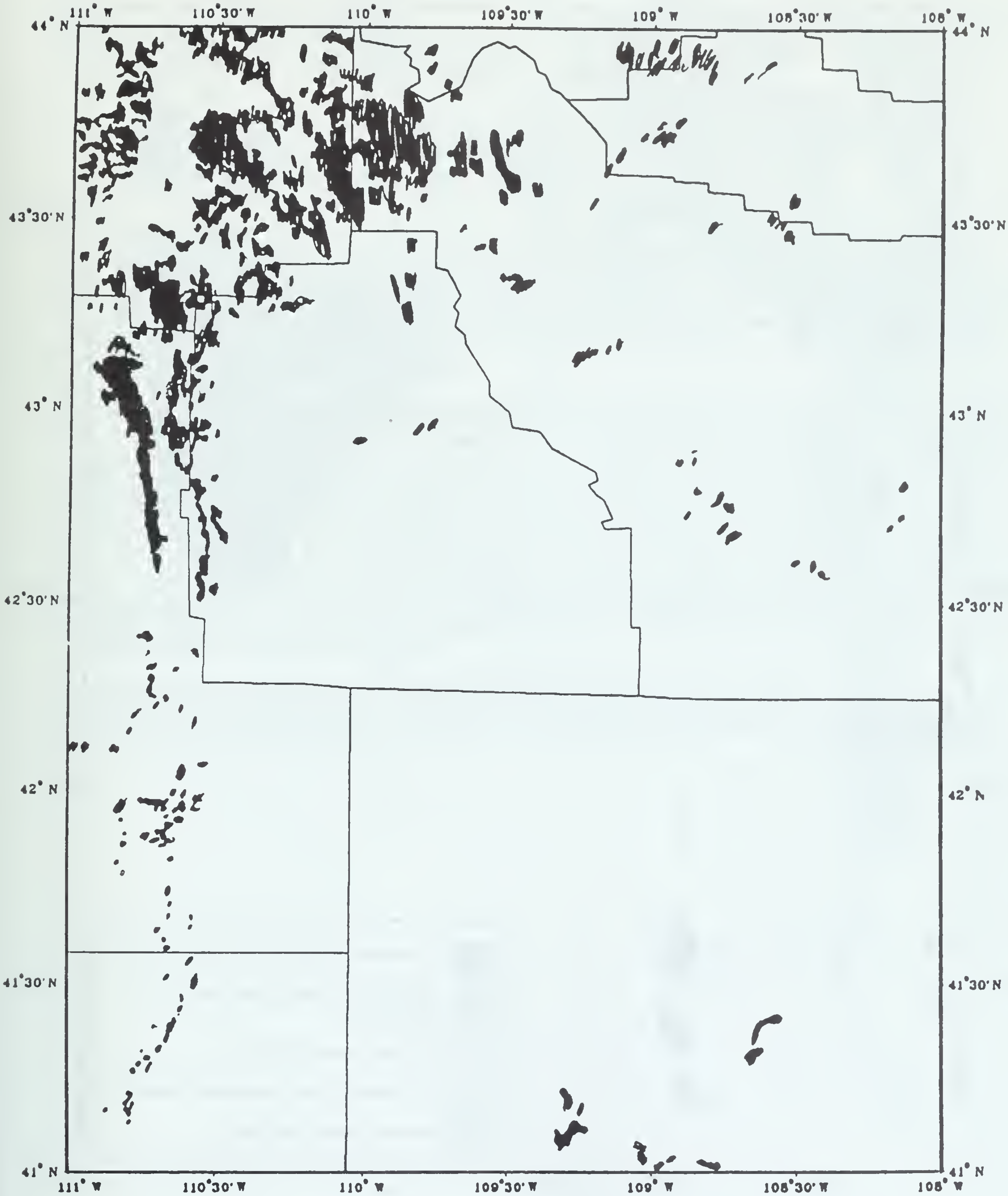

Figure 8. Location map potential landslide areas in the southwestern Wyoming regional study area.

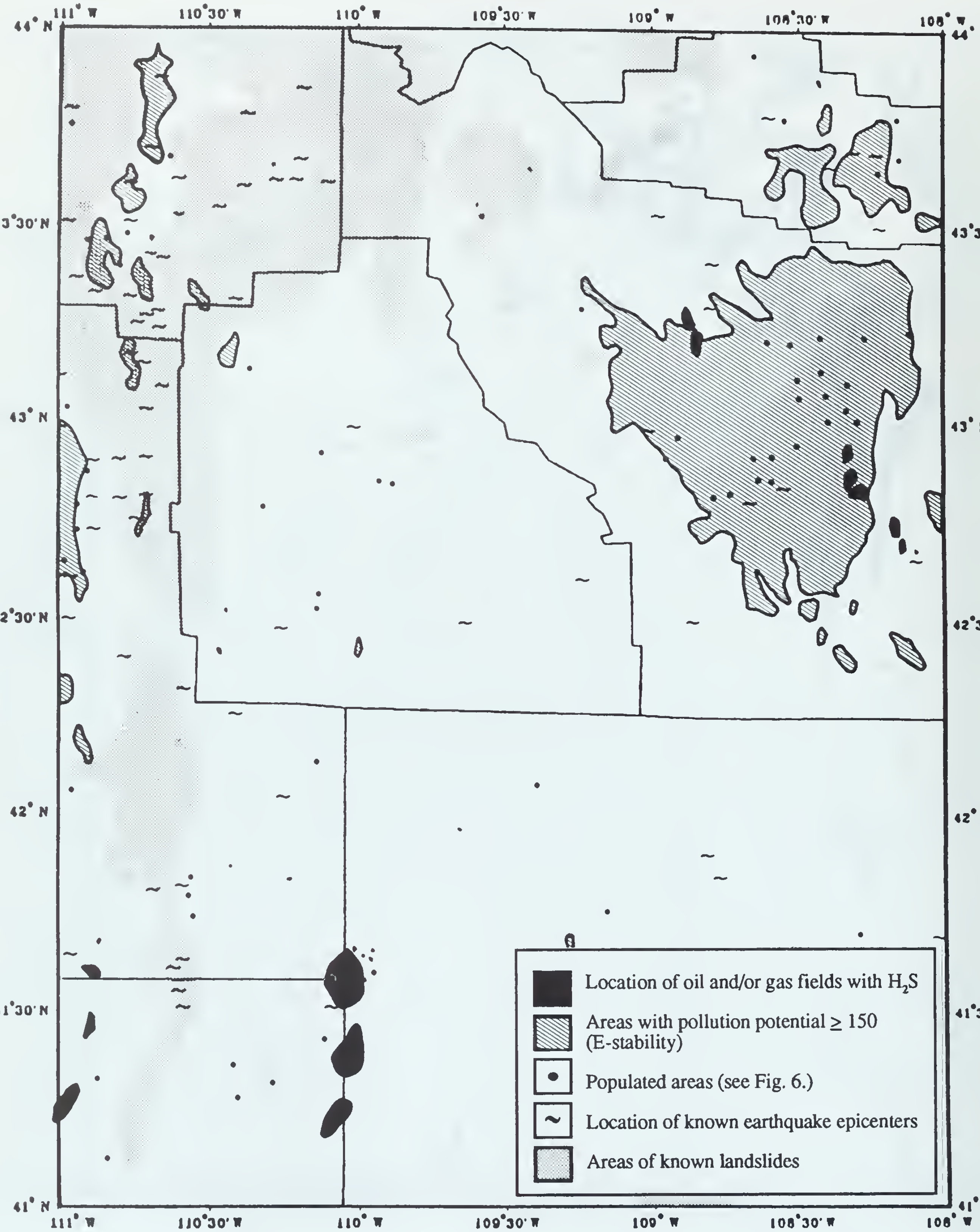

Figure 9. Complete overlay of all risk factors.

SUMMARY AND CONCLUSIONS

Potential air quality impacts associated with land management alternatives must be considered and evaluated as required under a number of Federal laws such as the Clean Air Act, the Wilderness Act, the Federal Land Policy and Management Act, the Forest Management Act, and NEPA. The evaluation of air quality impacts can be organized as a multilevel or tiered approach, including:

Level I — Regional Risk Identification
Level II — Source-Specific Screening
Level III — Source-Specific Diagnostic Modeling
Level IV — Source-Specific Prediction and Real-Time Emergency Assessment

The objective of this study was to perform a Regional Risk Identification Analysis relative to the development of H_2S-contaminated oil and gas resources in southwestern Wyoming. The analysis included compiling map overlays which depict various risk-related factors, such as existing sour fields, geologic hazards, population centers, and modeled meteorological dispersion potentials. Comparing these factors allowed the delineation of areas where air quality-related resource development risk is high or low. Maps of each parameter were combined to aid Federal decisionmaking.

In general, H_2S-contaminated resource development risk is low throughout the southwest Wyoming regional study area. Areas of higher risk, as identified by poorer air pollution dispersion potential, can be identified in portions of the southwest and northcentral quadrants of the study area. The results of this risk identification can be used in the preliminary evaluation of manage-ment alternatives relating to the development of H_2S-contaminated fossil fuel resources in the study area. From this analysis, well field simulations requiring detailed dispersion analyses and the collection of on-site meteorological data have been proposed for the BLM Kemmerer Resource Area. These are suggested in instances where poor dispersion potential, high H_2S concentrations, and population centers coincide. In these cases, it is anticipated that more detailed planning, e.g., the Environmental Impact Analysis, will utilize a Level II screening technique. If warranted, the actual development plan, e.g., lease agreement or contingency plan, may include Level III or Level IV considerations depending on the severity of the risk.

This paper illustrates only one specific use of the air quality modeling techniques we have developed. TA-PAS represents a comprehensive set of computer-based, graphic-oriented tools that can be used for many geographic information land systems.

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16. Abstract (Limit: 200 words)

Dangerous concentrations of hydrogen sulfide (H_2S) gas can occur through accidental release of 'sour' natural gas from wells and pipelines. Local, terrain-influenced, meteorological conditions can control the seriousness of these events.

In order to plan the development of H_2S-contaminated natural gas fields in Wyoming, the U.S. Bureau of Land Management (BLM) had to identify areas where air-quality impacts (dangerous concentrations) were likely and unlikely.

BLM performed a regional risk analysis in two environmental impact statements, in which maps of H_2S formations, geological hazards, population centers and meteorological dispersion potential were overlayed to highlight areas where air quality risks were high or low. Air quality modeling was conducted using component models of the Topographic Air Pollution Analysis System (TAPAS) developed by the U.S. Forest Service, BLM, and Colorado State University.

17. Document Analysis a. Descriptors

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Hydrogen sulfide 0702
Gas wells 0809
Gas fields 0809
Gas pipelines 1505
Air pollution 1302

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H_2S

c. COSATI Field/Group

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